

### Abstract

This is a short note on the *spatiotemporal complexity* of the dynamical state(s) of the universe at subhorizon scales (up to 300 Mpc). There are reasons, based mainly on infrared radiative divergences, to believe that one can encounter a flicker noise in the time domain, while in the space domain, the scaling laws are reflected in the (multi)fractal distribution of galaxies and their clusters. There exist recent suggestions on a unifying treatment of these two aspects within the concept of spatiotemporal complexity of dynamical systems driven out of equilibrium. Spatiotemporal complexity of the subhorizon dynamical state(s) of the universe is a conceptually nice idea and may lead to progress in our understanding of the material structures at large scales.

PACS numbers: 98.65.-r, 02.50.-r, 05.40.+j

IFUG-26/94 [ $\mathcal{HCR}$ ]; Nuovo Cimento B 110, 457-459 (April 1995)

astro-ph/9411112

# Spatiotemporal complexity of the universe at subhorizon scales

Haret C. Rosu

Instituto de Física de la Universidad de Guanajuato,  
Apdo Postal E-143, 37150 León, Gto, México

The problem of large scale structure of the universe, that is the understanding of the hierarchical large-scale clustering of galaxies, is one of the fundamental topics in modern cosmology [1].

At subhorizon scales of less than about 300 Mpc the structure of the universe, as reflected, e.g., in the two-point correlation functions of galaxies, cluster of galaxies, and quasars, shows a common fractal behavior of the type  $r^{-\gamma}$  with  $\gamma \sim 1.8$ . There exists already an extensive ‘(multi-) fractal’ literature on detailed aspects of the scaling properties of the large-scale structure [2]. Fractals are not the only candidates in providing a quantitative analysis of the subhorizon cosmological structure. Various kinds of percolations [3] as well as nonlinear diffusions either in the same percolation approach or defined through some nonlinear- noisy differential equations expressing large-scale turbulent/stochastic behavior [4] are powerful alternatives. For example, the above-mentioned result on the  $\gamma$  exponent is close both to the fractal dimension of self- similar percolation clusters ( $d_f= 1.89$ ) and to the fractal dimension of the hull of the diffusion front ( $d_f= 1.75$ ).

An interesting and far from innocuous question that one can ask is the nature of the dynamical state(s) of the Universe [DSU] at subhorizon scales. It is the goal of this note to provide some general heuristic arguments concerning the DSU. The arguments are based on a number of interesting results/claimings scattered in the literature of several distinct topics. Our point here is to emphasize the connection of the DSU problem with the general framework of *spatiotemporal complexity* of dynamical systems in nonequilibrium conditions,

such as growth phenomena. Spatiotemporal complexity is a concept that applies to a great variety of physical systems displaying both fractal scaling behavior and (generalized) flicker noise. For nonequilibrium steady-states entailing the two features the self-organized criticality (SOC) has been proposed as an explanation [5]. Very recently, Maslov, Paczuski, and Bak [MPB] [6] formally established the relationship between spatial fractal behavior and ‘long-range’ temporal correlations for a broad range of nonequilibrium models (not necessarily of SOC type). They used the language of avalanche activity, but in fact this general result can be obtained by means of fractal renewal processes too as shown, actually before MPB, by Lowen and Teich [LT] [7]. Both avalanche activity and fractal renewal processes can be used in subhorizon cosmology. Essentially the result of MPB and LT states that the time correlations in the local avalanche activity and the spatial activity are different cuts in the same spatiotemporal fractal. The power spectrum of the generalized flicker noise found by MPB is of the type  $S(f) \sim 1/f^{d_r}$ , where  $0 \leq d_r \leq 1$  can be expressed in a definite way in terms of the spatial dimension, the avalanche dimension, and the dynamical exponent [6].

Let us pass now to the subhorizon cosmological structures. One would like to identify somehow spatiotemporal fractals in this case. In the space domain we already referred to the fractal treatment of the hierarchical large-scale structure and we have to comment on the cosmic flicker noise.

There are more than 15 years since Press [8] has commented on the possible divergence of the low-frequency fluctuations in the light curves of quasars. Unfortunately the availability of

the astrophysical literature is quite limited for me at the present time so that I am not aware of the current situation on this matter. Therefore I shall turn to another possible line of putting into evidence some type of cosmic flicker noise. It has to do with the problem of infrared divergences (IRD) of the massless scalar Green functions in de Sitter space (or of minimally coupled scalar fields) [9], also known to occur in spatially flat FRW models with power law expansions [10]. Papers by Tsamis and Woodard [11] on the relaxation of the cosmological constant through infrared effects in quantum gravity are of relevance to this context too. To be quoted yet is a paper of Folacci [12], in which he showed that the massless scalar field theory on de Sitter space is not invariant under the symmetry group of that spacetime  $O(1,4)$ . Therefore the infrared divergence is a real one in contrast to what is happening in the case of the same theory on the four-dimensional sphere where it is only a gauge artifact. According to Folacci the same type of results applies for massive scalar fields for special values of the mass parameter.

The relevance of these IRD results for the subhorizon spatiotemporal complexity reveals itself when one is invoking the quite well-known theory of Handel on the quantum infrared origin of the  $1/f$  noise [13]. This theory is based on the infrared-type divergence present in all cross sections, and also in some autocorrelation functions due to interaction of the current carriers with massless infraquanta whose nature varies from case to case. Moreover, Handel generalized his approach to infrared radiative corrections to include the presence of a thermal radiation background [14] and commented on the so-called “gravidynamic quantum  $1/f$  noise”

[15], i.e., the effects of infragravitons in shaping the distribution of matter in space and time.

Finally, another source of  $1/f$  cosmic noise might be the volume Casimir effect [16] but I shall not address this point here.

In conclusion, what I have done in this note was to hint upon the two aspects required by the spatiotemporal complexity (spatiotemporal fractals) of the universe and I think that this concept should be seriously considered by authors dealing with subhorizon scales. The above heuristic comments on the spatiotemporal complexity of subhorizon organization of the universe might be useful for further more detailed insight into a problem of much current interest in astrophysics and cosmology. It would be of interest to determine the scales at which the universe is trapped into self-organized states, if any.

## Acknowledgements

This work was supported in part by the CONACyT Project 4862-E9406. The author is grateful to Professors R.P. Woodard and P.H. Handel for kindly providing him with their papers.

## References

- [1] P.J.E. Peebles, *The Large Scale Structure of the Universe* (Princeton University Press, Princeton, NJ, 1980); *Principles of Physical Cosmology* (Princeton Univ. Press, Princeton, NJ, 1993)
- [2] S. Borgani et al., Phys. Rev. E **47**, 3879 (1993); S. Borgani, “Scaling in the Universe”, Phys. Rept **251**, 1 (1995), and references therein (available also as astro-ph/9404054).

- [3] B.A. Ovrut, “Large scale structure and percolation theory”, UPR-0521T, 1992, Invited talk at the XV Int. Warsaw Meeting on Elementary Particle Physics, Kasimierz, Poland, May 25-29, 1992
- [4] S.N. Gurbatov, A.I. Saichev, and S.F. Shandarin, Mon. Not. R. Astron. Soc. **236**, 385 (1989); A. Berera and L.Z. Fang, Phys. Rev. Lett. **72**, 458 (1994)
- [5] P. Bak, C. Tang, and K. Wiesenfeld, Phys. Rev. Lett. **59**, 381 (1987); Phys. Rev. A **38**, 364 (1988)
- [6] S. Maslov, M. Paczuski, and P. Bak, “Avalanches and 1/f noise in evolution and growth models”, Phys. Rev. Lett. **73**, 2162 (1994)
- [7] S.B. Lowen and M.C. Teich, Phys. Rev. E **47**, 992 (1993)
- [8] W.H. Press, Commun. Astrophys. **7**, 103-119 (1978)
- [9] T.S. Bunch and P.C.W. Davies, Proc. R. Soc. A **360**, 117 (1978)
- [10] L.H. Ford and L. Parker, Phys. Rev. D **16**, 245 (1977); V. Sahni, Class. Quantum Grav. **5**, L113 (1988) and references therein.
- [11] N.C. Tsamis and R.P. Woodard, “The physical basis for infrared divergences in inflationary quantum gravity”, Class. Quantum Grav. **11**, 2969 (1994); “Strong infrared effects in quantum gravity”, Ann. Phys. **238**, 1 (1995)
- [12] A. Folacci, Phys. Rev. D **46**, 2553 (1992)

- [13] P.H. Handel, Phys. Rev. Lett. **34**, 1492 (1975); Phys. Rev. A **22**, 745 (1980)
- [14] P.H. Handel, Phys. Rev. A **38**, 3082 (1988)
- [15] P.H. Handel, in *Noise in Physical Systems and 1/f Noise*, Eds. A. D'Amico and P. Mazzetti, (Elsevier, 1986); S. Weinberg, Phys. Rev. **140B**, 516 (1965)
- [16] I. Yu. Sokolov, astro-ph/9405060 and Phys. Lett. A **223**, 163 (1996)